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Influence of Rhizosphere Ionic Strength on Mineral Composition, Dry Matter Yield and Nutritive Value of Forage Chicory

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With 1 figure and 4 tables

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Abstract

Animal manure and urine deposition can cause localized patches of high ionic strength (IS) soil in pastures, influencing plant production, nutritive value and sward composition. Chicory (*Cichorium intybus* L.) appears to thrive in high-nutrient input situations, but no information is available on chicory response to increasing IS. In a greenhouse experiment, we evaluated the effect of rhizosphere ionic strength (0.9, 4.0, 8.0 and 12.0 dS m^{-1}) on productivity and nutritive value of chicory. Dry matter production decreased linearly as IS increased. Shoot concentrations for Ca, Na and Cl increased as IS increased. All mineral concentrations, except Cu, were substantially higher than or equal to the highest concentrations reported for forages. At all IS, nitrate-N and K exceeded maximum recommendation for ruminant diets. The sodium level could be high enough to reduce dry matter intake at the highest IS level. Crude protein and energy estimates indicate chicory would support production levels equivalent to those of other high-quality forages. *In vitro* organic matter disappearance increased as IS increased. Chicory as a component of a forage mixture could help stabilize forage yield in pastures and also shows promise for use as a nutrient mop in feedlot areas, where excess soil nutrients are a problem.

Key words: chicory — dry matter yield — mineral content — nutritive value — soil salinity

Introduction

Elevated soil salinity influences growth of both shoots and roots and alters mineral nutrient composition of many crop and pasture species (Grattan 1994, Esechie and Rodriguez 1999, Mer et al. 2000). Salt-affected plants are generally characterized by dark green leaf coloration and reduced leaf size followed by a general reduction in plant size (Francois 1999). Depending on the source (Na^{+}/Ca^{2+} and Cl^{-}/SO_4^{2-}), salinity was shown to increase or decrease the uptake of Na^{+}, Cl^{-}, NO_3^{-}, Ca^{2+}, Mg^{2+}, and K^{+} (Grattan 1994, Marschner 1986), which in turn may have a marked effect on forage nutritive value.

In a permanent pasture ecosystem where grazing livestock recycle nutrients, some nutrients accumulate in soil to levels exceeding requirements for optimal growth of common forage species (Haynes and Williams 1993, Whitehead 1995). Manure and urine deposition has been shown to elevate salinity levels compared to adjacent unfouled grassland, especially in the uppermost soil layer (Lavado and Taboada 1987, Chaneton and Lavado 1996). In the flooding pampas grasslands of Argentina, salinity levels increased under grazing in both lowland and upland sites from 1.03 and 0.83 to 3.88 and 6.85 dS m^{-1}, respectively (Chaneton and Lavado 1996), well above the salt tolerance threshold of many forage species (Francois and Maas 1999). Overgrazing, especially in arid and semiarid regions, causes a progressive salinization of the soil, where natural vegetation becomes sparse or is eliminated over time (Szabolcs 1994).

Soil salinity is also a concern when excessive amounts of manure, from confinement operations, are applied to croplands, with the affect being heightened on clay-type soils and in dry climates (Davis et al. 1997). Chang et al. (1991) showed soil electrical conductivity and sodium absorption ratio increased as manure application rates increased on cropland in Alberta, Canada. Soil salt build-up is

[1] Mention of trade or proprietary names is for the convenience of the reader and does not imply endorsement by USDA or VPI, and does not imply their approval to the exclusion of other products that may also be suitable.

also a concern with regard to manure composting and abandoned feedlots (Eghball and Power 1994). Development of means to capture excess nutrients, other than direct soil application, would be beneficial both economically and environmentally. David Barker, Ohio State University (personal communication), suggests that there is a need for plants that sequester or accumulate nutrients under the soil conditions encountered in functioning or abandoned feedlots.

Chicory (*Cichorium intybus* L.) is a plant of Mediterranean origin (Vavilov 1992) and might contain water and/or salinity stress tolerance mechanisms as a result of evolutionary processes. When included in a cool-season sward mixture, chicory can improve dry matter availability to grazing animals during the summer when cool-season forage growth slows or stops (Lancashire and Brock 1983, Collins and McCoy 1997, Belesky et al. 1999). It contains high levels of minerals (Crush and Evans 1990, Belesky et al. 2001), suggesting that high nutrient inputs are needed to sustain production, especially on soils of marginal fertility (Belesky et al. 2001). 'Grassland Puna' chicory responds to mineral fertilizer in terms of higher nutritive value, growth and mineral content (Belesky et al. 1999, 2001, Collins and McCoy 1997, Clark et al. 1990). Information on the responses of forage chicory to salinity or increasing ionic strength in the rhizosphere is lacking. Insight into the response of chicory to excess nutrient-induced salt stress is needed because of the possible importance of chicory in pasture systems in the eastern US and the need for plant resources to sequester or accumulate nutrients on feedlot/dry-lot restoration sites (David Barker, Ohio State University, personal communication). The objective of our greenhouse experiment was to investigate the influence of ionic strength in the rhizosphere ($IS = 0.9–12.0\ dS\ m^{-1}$) on productivity and nutritive value of forage chicory. We present plant dry matter production, mineral composition, important macronutrient relationships, crude protein (CP), *in vitro* organic matter disappearance (IVOMD), metabolizable energy of feed (MEF), total non-structural carbohydrate content (TNC) and NO_3-N as function of ionic strength.

Materials and Methods

Experimental set-up

Pots (3.2-l capacity) containing 1.4 kg of potting mix (Premier Horticulture Inc., Red Hill, PA) were seeded with forage chicory (*Cichorium intybus* L. cv. Grasslands Puna). Pots were randomized on tables in a greenhouse (average day/night temperatures were set to 25/18 °C, relative humidity 50 %) on 5 June 2000, watered daily with deionized water, and thinned, after 6 days, to 7 seedlings pot^{-1} before treatments were imposed. Treatments were four IS nutrient solutions (0.9, 4, 8 and 12 $dS\ m^{-1}$), which were applied by irrigation. The composition of the nutrient solution was as follows: 1.5 mM $Ca(NO3)_2$; 1 mM NH_4NO_3; 0.5 mM KH_2PO_4; 3 mM KNO3; 0.5 mM $MgSO_4$; and micronutrients supplied according to the Long Ashton formula (Hewitt 1966). Projected ISs were obtained by addition of appropriate quantities of $NaCl/CaCl_2$ solution (1 : 1 M ratio) to give final concentrations of 0, 11.5, 29.5 and 51.0 mM $NaCl/CaCl_2$. The pH of all nutrient solutions was adjusted to 6.0 using 1 M NaOH. The four treatments (0.9, 4, 8 and 12 dSm^{-1}) each had 16 replicate pots for a total of 64 pots in this experiment. The different IS treatments were introduced gradually over 3 days (one-third of the IS on each day) in order to prevent osmotic shock to the plants. Throughout the experiment (41 days), pots were watered twice daily with the nutrient solution (300–500 ml) according to treatment. Pots were free draining from the bottom to minimize salt build-up in the growth media.

Harvest and measurements

At each harvest date (20, 27, 34 and 41 days after seeding), four replicate pots from each treatment were harvested. Shoots were severed from the roots, and lower stalks were rinsed with deionized water and blotted dry before measurements of leaf area were conducted using an image analyser (Agimage analysis, Decagon Devices Inc., Pullman, WA). Roots were extracted and washed thoroughly with water to remove adhering particles from the potting mix. Shoots and roots were oven-dried at 65 °C for a minimum of 48 h and dry weights recorded.

Shoots and roots were ground to pass a 0.5-mm screen and kept in sealed plastic bags until analysis. For total mineral ion concentrations, 50–100 mg of sample was weighed into individual Teflon containers. To each container with tissue, 1.0 ml of 15.8 M HNO_3 was added and a microwave digestion procedure was followed (Kingston and Jassie 1988). Digested solutions were brought to a final volume of 10.0 ml with distilled deionized water, filtered and stored in plastic tubes at 5 °C until analysed for mineral element content using ICP (Jobin Yvon Model JY 46P ICP, Longjumeau, France). Total nitrogen contents in shoot and root tissues were determined using a Carlo Erba analyser (Carlo Erba Ea1108 CHNS Analyzer, Fisons Instruments, Beverly, MA).

Soluble anions ($NO3^-$, Cl^-) were extracted by weighing 50–100 mg of ground shoot and root tissues into individual plastic scintillation vials, adding 10 ml of distilled deionized water, sealing the vials and placing them in a hot water bath (65 °C) for 1 h. Extracts were filtered through no. 1 Whatman filter paper and kept frozen at −10 °C until analysed. Nitrate and Cl^- were determined by ion chromatography with suppressed conductivity (Dionex DX 500 ion chromatography, AS 14 4 mm anion column).

Other nutritional parameters were determined as follows: dry matter (DM) and organic matter (OM) (AOAC 1990), total N (Carlo Erba Ea1108 CHNS Analyzer), *in vitro* organic matter disappearance (IVOMD) (Tilley and Terry 1963, Moore 1970), NO_3-N (Consalter et al. 1992) and TNC (Smith 1981) as modified by Denison et al. (1990). Calculations included: crude protein (CP) = (total N × 6.25) and metabolizable energy of feed (MEF) = (0.92 × IVOMD) − 1.2] × 0.15 (MAFF 1987).

Statistical analysis

Data were statistically analysed using ANOVA general analysis of variance (SAS Institute 1999). Sources of variation were the effect of IS, harvest date (HD), and the interactions of IS and HD. Data were also analysed using single degree of freedom orthogonal polynomial contrasts for the influence of IS on DM, mineral composition, mineral relationships, nutritive variables (IVOMD, MEF, and TNC) and NO_3-N.

Results and Discussion

The influences of IS, HD, and their interaction (IS × HD) on nutritional variables are presented in Tables 1 and 2. Where IS × HD was significant for a variable, this indicated that the influence of IS on that variable was not persistent in trend or magnitude over time. However, IS × HD interactions may be of little biological significance from an animal nutrition standpoint as, within a properly managed pasture environment, individual plant species are likely to have biomass of varying age. Consequently, as animals graze they will consume forage of similar variability, thus justifying the use of average values across time, when considering overall nutritional value of a particular forage. Orthogonal polynomial contrasts showed that response to IS was mostly quadratic (with the exception of K and MEF concentration in DM), suggesting the influence of IS was either less at higher IS levels or reached a critical IS.

Dry matter productivity

Dry matter production in chicory increased over time in all IS treatments and decreased significantly with increasing IS in the rhizosphere (Fig. 1). The DM production decrease was linear ($P = 0.0004$, $R^2 = 0.9936$) with increasing IS, irrespective of harvest date. Increasing IS from the control level (0.9 dS m^{-1}) to 4, 8 and 12 dS m^{-1} resulted in 13, 33, and 46 % decreases in DM production, respectively (Fig. 1). The highest salinity level reported for grazed pasture is 6.85 dS m^{-1} (Norman 1991, Chaneton and Lavado 1996), which would result in approximately a 30 % reduction in chicory DM production. Francois and Maas (1999) classified plants from sensitive to tolerant, based on yield response to salt-affected soils. Using their classification system, Grassland Puna chicory is moderately tolerant to salinity, making it a good candidate for use in situations where soil salinity or nutrient concentrations are greater than normal.

Mineral composition

All shoot mineral concentrations except Na were influenced by time (Table 1) and decreased as plants matured. Mineral concentrations in plant tissue are a function of growth and uptake rates. When growth rate exceeds uptake rate, in most instances, nutrient dilution occurs (Jarrell and Beverly 1981). Increasing level of IS in nutrient solution significantly affected, with the exception of K, all mineral concentrations in shoot DM (Table 1).

Table 1: Analysis of variance and significant effects of ionic strength (IS), harvest date (HD), and their interaction (IS × HD) on mineral concentrations in the shoots of chicory plants. Also given is the orthogonal polynomial contrast with a single degree of freedom for the influence of IS rate

Effect	d.f.	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})	S (g kg^{-1})	Na (g kg^{-1})	Cl (g kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
Ionic strength (IS)	3	***	**	ns	**	***	***	***	*	***
Linear	1	ns	ns	ns	ns	***	ns	***	ns	ns
Quadratic	1	***	***	ns	***	**	***	***	*	***
Harvest date (HD)	3	***	***	***	***	***	ns	*	***	**
IS × HD	9	ns	*	*	ns	**	ns	***	**	**

* Significant at the 0.05 level. ** Significant at the 0.01 level. *** Significant at the 0.001 level.

Table 2: Analysis of variance and significant effects of ionic strength (IS), harvest date (HD), and their interaction (IS × HD) on shoot mineral ratios, dry matter (DM), crude protein (CP), *in vitro* organic matter disappearance (IVOMD), metabolized energy (ME), total non-structural carbohydrate (TNC) and nitrate nitrogen (NO_3-N). Also given is the orthogonal polynomial contrast with a single degree of freedom for the influence of IS rate

Effect	d.f.	N:S ratio	Ca:P ratio	K:(Ca + Mg) ratio	DM (g pot^{-1})	CP (g kg^{-1} DM)	IVOMD (g kg^{-1} DM)	MEF (MJ kg^{-1} DM)	TNC (g kg^{-1} DM)	NO_3-N (g kg^{-1} DM)
Ionic strength (IS)	3	***	***	***	***	*	*	*	***	***
Linear	1	***	ns	ns	***	ns	ns	**	***	***
Quadratic	1	***	***	***	***	**	**	ns	***	***
Harvest date (HD)	3(2)†	***	***	***	***	***	ns	ns	***	***
IS × HD	9(6)†	***	*	**	***	***	ns	ns	***	***

*Significant at the 0.05 level. ** Significant at the 0.01 level. *** Significant at the 0.001 level.
†Value in parentheses is d.f. for IVOMD and MEF.

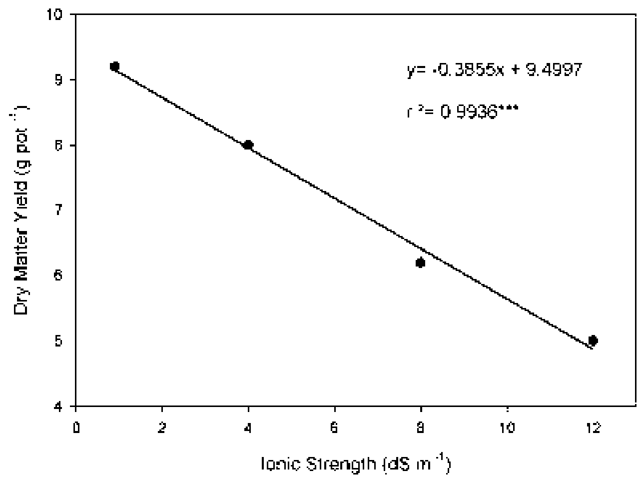

Fig. 1: Effect of increasing rhizosphere IS on shoot dry matter production of forage chicory

Means and ranges of individual mineral concentrations averaged across HD are presented in Table 3. Concentrations of Ca, Na, Cl, Cu and Zn increased in shoot tissue with increasing IS. The increase was most pronounced in the cases of Na and Cl and corresponded to the increase in their concentrations in the nutrient solution (Table 3). Phosphorus, S and Mg concentrations decreased with increasing IS. The quadratic response of most mineral concentrations to increasing IS suggested a threshold or that there was a non-linear response to increasing IS, at either the lower or higher range of IS (Tables 1 and 3). For example, concentrations of Ca, P, Mg, Cu, and Zn were not affected until IS was higher than 4 dS m^{-1}. Concentrations were not affected by increasing IS from 8 to 12 dS m^{-1} in the cases of P, Mg, S, and Zn. For Na and Cl, there was an increase in concentrations with every incremental increase in IS, although the response was quadratic rather than linear (Tables 1 and 3). Mineral concentrations were generally higher than those reported for the same plant species grown under field conditions (Belesky et al. 2001). Under the conditions of this experiment, Grasslands Puna had an unlimited supply of nutrients, which would also occur in frequently fertilized pastures, soils receiving excessive manure application and under feedlot conditions. Given our results, further research should be considered to evaluate chicory as a bioremediator. Further, can chicory forage, grown under salinity stress, be utilized as an animal feed, either alone or mixed with other diet components?

Calcium levels (Table 3) were higher than typically found in most forage (Stout et al. 1977, Spears 1994)

Table 3: The influence of rhizosphere ionic strength on mineral concentrations (Ca, P, K, Mg, S, Na, Cl, Cu, and Zn) in the shoots of chicory plants. Values are means and ranges (in parentheses) across the harvest times

	$g\ kg^{-1}$ DM							$mg\ kg^{-1}$ DM	
IS ($dS\ m^{-1}$)	Ca	P	K	Mg	S	Na	Cl	Cu	Zn
0.9	18.6	11.6	158.5	3.3	4.1	6.1	13.6	6.9	44.2
	(15.9–22.4)	(5.3–22.1)	(83.9–255.6)	(2.6–4.6)	(3.3–5.1)	(3.4–12.8)	(7.7–23.1)	(3.5–21.7)	(30.8–80.9)
4.0	20.0	11.1	153.4	3.3	3.4	18.5	42.9	6.9	49.8
	(16.2–25.0)	(5.6–20.8)	(102.5–273.1)	(2.4–4.5)	(2.1–4.8)	(11.8–41.9)	(29.5–54.2)	(4.3–15.2)	(36.9–64.1)
8.0	23.8	10.2	155.4	3.0	3.5	33.9	51.8	7.2	65.8
	(15.8–28.8)	(6.3–16.2)	(101.1–216.3)	(2.0–4.7)	(2.5–4.5)	(20.3–50.3)	(38.6–60.2)	(5.2–9.8)	(54.6–97.2)
12.0	28.6	9.9	140.3	2.8	3.5	56.2	57.9	9.2	65.9
	(14.1–34.5)	(6.2–16.3)	(94.4–185.9)	(1.4–4.4)	(2.9–5.2)	(36.1–97.1)	(51.2–63.8)	(6.0–17.8)	(44.4–93.1)
Linear	ns	ns	ns	ns	***	ns	***	ns	ns
Quadratic	***	***	ns	***	**	***	***	*	***

* Significant at the 0.05 level. ** Significant at the 0.01 level. *** Significant at the 0.001 level.

across all treatments, increased as ionic strength increased, and were higher than the concentrations found in field-grown forage chicory (Belesky et al. 2001). Calcium levels of up to 2.0 % of the dry matter are considered acceptable in ruminant diets (National Research Council 1985) and clearly all treatments approached or exceeded this level. Shoot content would certainly meet animal needs for any level of performance. However, the high Ca concentrations in chicory may influence metabolism of P, Mg and some trace minerals (National Research Council 1980, Alfaro et al. 1988).

Shoot P content decreased as ionic strength increased (Table 3) and P levels were much higher than would typically be seen in other forages and field-grown chicory (Stout et al. 1977, Spears 1994, Belesky et al. 2001). Concentrations found in the chicory shoots, across all treatments, far exceeded domesticated ruminant requirements.

Shoot K was not affected by IS level and ranged from 158.5 to 140.3 g kg^{-1} in the 0.9 to 12.0 IS treatments. These extremely high concentrations are approximately 10 $\times$ the concentrations reported by Belesky et al. (2001) for chicory under field conditions. Generally, a diet containing 7 g K kg^{-1} DM will meet or exceed the requirements of most classes of sheep and cattle. The reported maximum tolerable level of K in the diet of cattle and sheep is 30 g kg^{-1} (National Research Council 1980, 1996). The K level found in our experiment greatly exceeded the maximum tolerable level for ruminants and deserves careful consideration. Chicory clearly has the ability to accumulate extraordinarily high K concentrations. The chicory in this experiment was grown under mineral-rich conditions and most of the minerals (not just K) were higher in concentration than would be considered normal in most forage plants (Stout et al. 1977, Spears 1994, Belesky et al. 2001). From our observations, two main points should be considered: (1) IS did not affect K concentration in chicory shoot material, and (2) chicory forage accumulates high levels of K, which could have a negative influence on animal health and performance.

Shoot Mg content decreased as IS increased (Table 3) and, although higher than the average in most forage, was within typical ranges (Stout et al. 1977, Spears 1994). Belesky et al. (2001) found higher Mg concentrations in field-grown chicory than we observed. Forage Mg levels of 2 g kg^{-1} are considered adequate for all classes of cattle and sheep (National Research Council 1985, 1996). Shoot material contained adequate Mg concentrations across all treatments and never exceeded the maximum tolerable level of 4 g kg^{-1} (National Research Council 1996).

Sulphur in shoots ranged from 4 g kg^{-1} in the 0.9 IS treatment to a low of 3 g kg^{-1} in the 12 IS treatment (Table 3). The dietary requirement for cattle or sheep does not exceed 2.6 g kg^{-1} (National Research Council 1985, 1989, 1996). The maximum tolerable level in ruminants appears to be 4 g kg^{-1} (National Research Council 1980), which was not exceeded in any treatment group. Belesky et al. (2001) found comparable S concentrations in field-grown chicory. Given these findings, S content in chicory should be monitored closely.

Sodium and chlorine levels increased in shoot material as IS level increased (Table 3) and ranged from 6.1 and 13.6 g kg^{-1} DM in the 0.9 IS treatment to 56.2 and 57.9 g kg^{-1} DM in the 12 IS treatment, respectively. These concentrations far exceed the requirements of both cattle and sheep (National Research Council 1985, 1996) and are much higher than typical for forage (Stout et al. 1977, Spears 1994). In the case of IS 12, the 56.2 g kg^{-1} DM concentration of Na exceeded the dairy cattle maximum tolerable level of NaCl by 16 g kg^{-1} DM (National Research Council 1980) and may reduce dry matter intake. In all other treatments (0.9, 4 and 8 IS), no adverse effects would be expected, even though the Na requirement for all classes of domesticated ruminants does not exceed 2 g kg^{-1} DM (National Research Council 1985, 1989, 1996).

Shoot Cu content ranged from 6.9 mg kg^{-1} in the 0.9 IS treatment to 9.2 mg kg^{-1} in the 12 IS treatment (Table 3). Belesky et al. (2001) found higher concentrations of Cu in forage chicory under field conditions. The minimum Cu requirement for cattle is 10 mg kg^{-1} but higher levels may be needed in cases where forages contain high amounts of S and/or Mo (National Research Council 1989, 1996). Sheep requirements range from 7 mg kg^{-1} in lactating animals to 9 mg kg^{-1} during pregnancy (National Research Council 1985). Based on Cu level alone, cattle requirements are not met under any IS treatment, while growing and pregnant sheep needs would only be met under the 12 IS treatment. If we take into account S level (Table 3) and Mo content (data not shown), ruminants consuming chicory grown under treatments 0.9, 4 and 8 IS would probably be deficient in Cu.

Chicory shoot Zn concentration increased with increasing IS and ranged from 44.2 to 65.0 mg kg^{-1} (Table 3). Spears (1994) reported much lower average concentrations for forages and Belesky et al. (2001) reported similar concentrations in chicory. Zinc concentrations across all treatments exceeded requirements for all classes of domesticated ruminants (33 mg kg^{-1} DM or less) and were well below maximum tolerable limits (National Research Council 1985, 1989, 1996). However, Mills and Dalgarno (1967) reported poor Zn utilization in diets containing 12–18 g kg^{-1} Ca. Calcium levels of this magnitude certainly occurred in our experiment and can occur in chicory under field conditions (Belesky et al. 2001).

Mineral macronutrient relationships

Salinity has been shown to alter mineral concentrations in shoot dry matter (Grattan and Grieve 1994, Esechie and Rodriguez 1999, Mer et al. 2000) and our experiment has confirmed this for forage chicory as well. Mineral uptake increases or decreases depending on the source and concentration of salts in the growth media. As a result, the ratio of minerals in shoot material may be changed and might interfere with absorption and metabolic function in livestock. Consideration of mineral nutrient ratios, such as N:S, Ca:P, and K:(Ca + Mg), is therefore important when assessing herbage nutritive value. These ratios were affected by IS, HD, and the length of time plants were subjected to increasing IS (Table 2). The response of these ratios to IS was quadratic, indicating a break in the correlation between increasing IS and increasing/decreasing ratios (e.g. no increasing N:S effects in response to IS after 4 dS m^{-1}; no decreasing effect on K:(Ca + Mg) ratio until IS reached 8 dS m^{-1}).

The ratio of N:S is often discussed when evaluating forage species for ruminant diets and was significantly influenced by IS (Table 4), with increased IS causing an increase in the N:S ratio. The increase in N:S ratio resulted from an enhanced N concentration with increased IS (data not shown) and a decline in S concentration (Table 3). Kincaid (1988) cites ratios of 15 : 1 for cattle and 10–12 : 1 for sheep as being adequate and, under our experimental conditions, the ratio of N:S was adequate across all treatments. Belesky et al. (2001) found the N:S ratio to be less than 10 : 1 in field-grown forage chicory except under high N fertilization.

A correct ratio of Ca:P is important from an animal nutrition standpoint. Kincaid (1988) indi-

Table 4: The influence of rhizosphere ionic strength on shoot N:S ratio, Ca:P ratio, K:(Ca + P) ratio, crude protein (CP), *in vitro* organic matter disappearance (IVOMD), metabolized energy of feed (MEF), total non-structural carbohydrate (TNC) and percentage nitrate nitrogen (NO_3-N) in the shoots of chicory plants. Values are means and ranges (in parentheses) across the harvest times

IS (dS m^{-1})	N:S ratio	Ca:P ratio	K:(Ca + Mg) ratio	CP (g kg^{-1} DM)	IVOMD (g kg^{-1} DM)	MEF (MJ kg^{-1} DM)	TNC (g kg^{-1} DM)	NO_3-N (g kg^{-1} DM)
0.9	11.7	1.8	3.4	296	768	10.4	64.9	8.2
	(7.5–16.1)	(0.9–3.1)	(2.0–5.3)	(183–398)	(638–915)	(8.6–12.5)	(12.7–136.3)	(0.9–14.1)
4.0	14.4	2.2	3.1	303	758	10.3	37.2	6.1
	(12.6–16.1)	(1.0–4.4)	(2.0–4.8)	(203–383)	(684–858)	(9.3–11.7)	(12.3–78.8)	(1.1–8.3)
8.0	14.4	2.5	2.8	307	784	10.6	32.9	5.8
	(12.1–18.3)	(1.5–4.4)	(1.7–3.8)	(227–372)	(740–864)	(10.0–11.7)	(15.1–50.3)	(2.4–7.3)
12.0	14.2	3.2	2.3	311	830	11.3	39.7	5.4
	(11.2–19.3)	(1.4–5.3)	(1.4–4.5)	(252–354)	(749–945)	(10.2–12.9)	(19.0–58.4)	(3.1–6.9)
Linear	***	ns	ns	ns	ns	**	***	***
Quadratic	***	***	***	***	**	ns	***	***

* Significant at the 0.05 level. ** Significant at the 0.01 level. *** Significant at the 0.001 level.

cated that a Ca:P ratio between 1.1 : 1 and 6 : 1 was desirable to insure proper metabolic function in cattle. The ratio of Ca:P was affected by growth medium IS (Table 4) and ranged from 1.8 (0.9 IS) to 3.2 (12 IS). This corresponds to an increase in Ca and a decrease in P concentrations as IS increased. Although IS influenced Ca:P, the ratio remained within the acceptable range across all treatments and did not appear to cause concern for chicory grown in high-salinity conditions. Belesky et al. (2001) found similar Ca:P ratios in chicory grown under field conditions.

The K:(Ca + Mg) ratio is also metabolically important from an animal standpoint, when expressed on a molar equivalent basis. When this ratio is greater than 2.2, the probability of grass tetany occurrence, particularly in lactating cattle, greatly increases (Grunes and Welch 1989). The K:(Ca + Mg) ratio in chicory shoot DM was affected by growth medium IS (Table 4). As IS increased, the ratio decreased from 3.4 to 2.2. The potential for grass tetany ran from very high in the 0.9 IS treatment to borderline in the 12 IS treatment. Belesky et al. (2001) found K:(Ca + Mg) ratios well below ours in chicory grown under field conditions. The major contributor to the high ratios in our experiment was the excessive shoot K.

Crude protein

Crude protein (N) was influenced by IS, with concentrations increasing as IS increased (Table 4). These findings are in agreement with those of Langdale and Thomas (1971) for bermudagrass (*Cynodon dactylon* L.) but disagree with the findings of Esechie and Rodriguez (1999) and Mer et al. (2000). Crude protein content across all IS treatments exceeded the requirement for sheep, beef and dairy cattle at all stages of production (National Research Council 1985, 1989, 1996) and also exceeded concentrations found in field-grown chicory by Belesky et al. (1999).

In vitro organic matter disappearance and metabolizable energy of feed

In vitro organic matter disappearance was increased by the 12 IS treatment (Table 4). However, all values are indicative of high quality forage and surpass IVOMD concentrations reported for chicory growing under field conditions by Belesky et al. (1999).

The effect of salinity on MEF (Table 4) mirrored that of IVOMD, as MEF was estimated from the IVOMD results. Animal performance is related to forage energy and estimation of MEF allows prediction of animal performance, when CP and mineral content are adequate. Based on MEF content alone, animal performance would be expected to be good across all IS treatments.

Non-structural carbohydrate

Forage total non-structural carbohydrate (TNC) content has been positively related to animal preference (Mayland et al. 2000). Increasing IS negatively influenced chicory TNC content (Table 4). The concentration of TNC within the 0.9 IS treatment corresponded to low to mid levels found in cool- and warm-season grasses, and legumes. Concentrations within the 4, 8 and 12 IS treatments related to low concentrations found in warm-season grasses and legumes (Moore 1994). Higher levels of TNC are indicative of a positive energy balance. The reduction of TNC levels in our experiment, within the salinity treatments, suggests an increased energy demand by chicory caused by salinity stress. This is reflected in the rise in IVOMD (Table 4), indicating a reduction in structural carbohydrate. Our findings suggest, based on palatability to grazers, that increasing IS may negatively affect animal acceptance of forage chicory.

Nitrate nitrogen concentration

Chicory is a member of the Compositeae family, members of which are known to be accumulators of NO_3^- (Wright and Davison 1964). Increasing rhizosphere IS negatively influenced shoot NO_3-N content and was extremely high across all treatments, ranging from 8.2 to 5.4 g kg^{-1} (Table 4). Hogg (1981) indicated that concentrations of around 2.3 g kg^{-1} were toxic and Belesky et al. (2000) suggested pure chicory swards receiving N fertilizer should be utilized cautiously. Our experiment also suggests that chicory has the potential for severe NO_3^- problems when grown under nutrient-rich conditions. Forages containing > 0.45 % NO_3-N should not be fed (Emerick 1988); however, ensiling reduces NO_3^- concentrations by 50 % (Hogg 1981) and could be utilized as a means of lowering toxicity.

Chicory dry matter production decreased linearly as IS increased. Rising IS increased the concentrations of Ca, Na, Cl, Cu and Zn and decreased the concentrations of P, Mg and S. All concentrations of minerals, except Cu, were either substantially higher than or equal to the highest concentrations reported for forages (Stout et al. 1977, Spears 1994), reaffirming the ability of chicory to sequester high levels of minerals (Belesky et al. 2001). Excess K and marginal Cu concentrations were the major mineral factors of nutritive concern. The relationships of N:S and Ca:P remained within acceptable limits, whereas K:(Ca + Mg) was above the recommended 2.2 : 1 ratio. Crude protein concentration exceeded animal requirements across all IS treatments and supports the high ability of chicory to sequester N when high levels are available. Both IVOMD and MEF were positively influenced by increased IS in the 12 IS treatment. Shoot TNC was negatively influenced by increasing IS, suggesting animal acceptance may be compromised. Across all IS treatments, NO_3-N concentration would be considered lethal to animals if consumed as the sole dietary component. Our results show that forage chicory is moderately tolerant to IS challenges in the rhizosphere and is capable of sequestering high levels of nutrients in environments where excesses occur.

Zusammenfassung

Einfluss der Ionenstärke in der Rhizosphäre auf die Mineralstoffzusammensetzung, den Ertrag und den Futterwert der Futter-Zichorie

Die Absatzflecken von Kot und Urin können engbegrenzte hohe Ionenstärken (IS) im Boden verursachen. Dieses beeinflusst den Aufwuchs, den Futterwert und die Zusammensetzung des Bestandes. Zichorie (*Cichorium intybus* L) hat ein hohes Nährstoffaneignungsvermögen, Informationen hinsichtlich einer zunehmenden IS sind kaum verfügbar. In einem Gewächshausversuch wurde die Wirkung der rhizosphärischen Ionenstärke (0,9, 4,0, 8,0 und 12,0 dS m^{-1}) auf die Produktivität und den Futterwert der Zichorie geprüft. Die Trockenmasseakkumulation nahm linear mit zunehmender IS ab. Die Gehalte im Spross an Ca, Na and Cl nahmen mit der IS zu. Alle mineralischen Konzentrationen außer Cu waren beträchtlich höher oder gleich zu den höchsten bekannten Gehalten in anderen Futterpflanzen. Zu jeder IS übersteigen die Gehalte an Nitrate-N und K die maximalen Empfehlungen für Wiederkäuer. Die Na-Konzentration der hohen IS könnte hoch genug sein, um eine Futteraufnahme zu reduzieren. Allerdings zeigten die Rohproteinwerte und die geschätzte Energie ein ähnlich hohes Niveau wie vergleichbare Qualitäten anderer Futterpflanzen. Die *in vitro* Verdaulichkeit der organische Substanz nahm mit zunehmender IS zu. Futter-Zichorie

könnte als eine Komponente in Futtermischungen zu einem ausgeglichenen Futterertrag führen, wobei problematische exzessive Nährstoffbereiche mit abgebaut werden könnten.

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